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Hohlraum glint and laser pre-pulse detector for NIF experiments using VISAR[a)]

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Laser pre-pulse and early-time laser reflection from the hohlraum wall onto the capsule (termed “glint”) can cause capsule imprint and unwanted early-time shocks on indirect drive implosion experiments. In a minor modification to the existing VISAR diagnostic on NIF a fast-response vacuum photodiode was added to detect this light. The measurements show evidence of laser pre-pulse and possible light reflection off the hohlraum wall and onto the capsule.

I. Introduction

The indirect drive scheme for inertial confinement fusion (ICF) utilizes a high-Z hohlraum (hollow can-shaped volume) surrounding the fuel capsule. Laser power directed at the inner wall of the hohlraum is converted to x-ray power which is absorbed by the capsule causing it to ablate and implode [1]. Inertial Confinement Fusion (ICF) experiments using the NIF laser[2] are primarily indirect drive. Laser power from a group of the NIF beams can specularly reflect off the wall of the hohlraum and be directed to the capsule. This process is called “glint” because it represents a flash of light from a shiny surface[3]. Laser intensity at the capsule of $I \geq 1\text{x}10^8$ W/cm^2 is sufficient to cause capsule imprint[4]. This can initiate growth of perturbations and enhance fuel / capsule mix. Recent hohlraum designs on NIF include gas-filled and nearly empty (called Near Vacuum Hohlraums or NVH[5]). Radiation hydrodynamic simulations of the early-time laser power show that in gas-filled hohlraums there is a short period of time (~0.2 ns) where glint can reach the capsule without absorption in the hohlraum gas / plasma. Modeling also shows that NVH targets are prone to glint throughout the laser pulse. Measurements of the wavelength shift and polarization of the scattered light close to 351 nm shows evidence of glint[6].

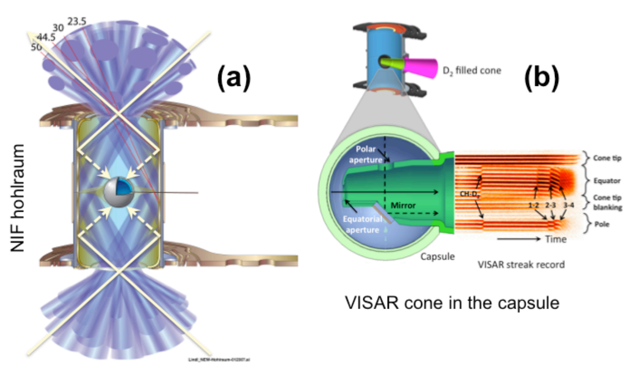

Figure 1. (a) NIF hohlraum showing "glint" - light reflecting off the hohlraum wall and onto the capsule. (b) shows the VISAR cone installed in the capsule.

In an effort to quantify the laser light that shines directly on the capsule in an indirect drive hohlraum target a simple Hamamatsu fast vacuum phototube detector was added to the existing NIF VISAR diagnostic[7]. VISAR is used to measure shock trajectories in materials and has a view from the inside of the capsule for the hohlraum experiments. Laser light incident on the capsule is attenuated as it transmits to the inside of the capsule. This light can then can be collected by the VISAR instrument. The measurements made over a number of experiments indicate two primary results: First, the detector indicates the presence of laser light in some experiments up to 8 ns before $T = 0$. This is likely laser pre-pulse but is at an acceptable level. Second, a high-density carbon (HDC) ablator shows a time-dependent signal which may indicate glint at a level in excess of what is allowed. The primary focus of this paper is to describe the operation of the instrument with a cursory discussion of the physics.

II. Diagnostic description

The diagnostic is a minor modification of the NIF VISAR diagnostic. VISAR (Velocity Interferometer System for Any Reflector) directs a 659 nm low-power laser down an optical path and into the hohlraum capsule. The light traverses the capsule wall (if transparent) where it reflects off the leading shock-front caused by x-ray ablation and shock compression. The reflected light propagates back up the optical path where it is directed to interferometers and streak cameras for detection.

Many of the diagnostics on NIF (including VISAR) were designed and built to meet carefully constructed requirements. Nevertheless, there have been a number of recent innovative modifications of these diagnostics which extend their capability. This diagnostic is an example of extending the use of VISAR.

VISAR is the only instrument on NIF with optical access to the inside of the capsule. This makes it particularly suited as a potential glint detector. Laser light incident on the capsule will be transmitted (after attenuation) through the capsule and emerge on the inside of the shell. The VISAR optics collect this light and make it available for detection.

Light collected with the VISAR optics from inside the capsule reaches a first mirror which is coated to reflect 659 nm light but transmits all other light. This makes it possible to detect 351 nm laser light (from NIF) from behind this first mirror. The detector used to measure the 351 nm light is a Hamamatsu vacuum phototube (model number is R1328U) with a response time of about 60 ps. Figure 2 (a) shows the diode mounted behind the first VISAR mirror. Several colored-glass filters and bandpass filters select the light observed by the diode. Signal from the diode is passed through a series of voltage dividers and into the 4 channels of a Tektronix DPO 7254 scope as shown in Fig. 2 (b). The use of 4 channels allows for a greater dynamic range.

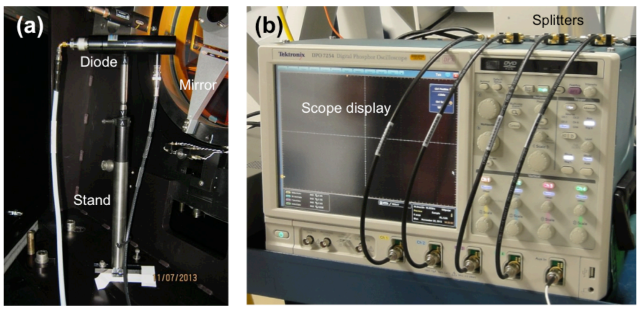

Figure 2. (a) Diode installed behind the VISAR mirror. (b) Scope and Voltage divider setup

III. Measurements

Figure 3 shows an example of the diode signal for NIF shot N150527 which used a CH capsule. The voltage traces have been scaled to account for the reduction from the voltage splitters. Thus, Channel 4 has been multiplied by 2, Chan-3 by 4, Chan-2 by 8 and Chan-1 by 16. Since Chan-4 has the maximum scope gain (5 mV/div) and maximum signal input this trace saturates at the lowest Voltage. Chan-4 also has the lowest noise floor at about 5×10^{-4} Volts. Chan-1 has the least scope gain of 60 mV/div so it doesn't saturate. The noise level of Chan-1 is about 200 times higher than Chan-4.

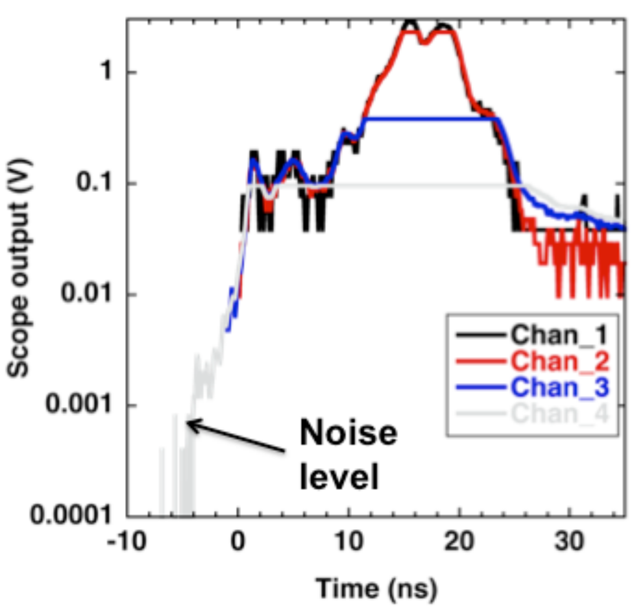

Figure 3. Plot shows the 4 scope channels that can achieve a dynamic range of nearly 10^4.

The approximate dynamic range is estimated by noting that the noise floor of Chan-4 is 5×10^{-4} Volts and that the saturation level for Chan-1 is 10 divisions x 0.06 mV / div = 0.6 V. The Voltage signal input to Chan-1 has been reduced by a factor of 8 relative to the Chan-4 signal. This means that Chan-1 saturates at effectively 4.8 V giving a dynamic range of 4.8 / 5×10^{-4} which is ~1×10^{-4}. This represents a large dynamic range and is one of the key features of this diagnostic. This large range in sensitivity is important for measuring laser pre-pulse and a glint signal which may have a large range of signal levels.

The scope signals are stitched together so that when one saturates the next one in sequence is used and so forth. The spatial size of the Voltage dividers introduces a small time delay between the signals which must be accounted for when stitching. Figure 4 shows an example of a stitched diode signal which has been converted to total power inside the capsule. The diode signal (blue) is plotted with the laser-power signal (black). Note that the diode begins to show power above the noise level at T = -8 ns, long before the laser pulse turns on at T = 0. This suggests laser-pre-pulse having an intensity of 1×10^4 W/cm^2 at the inner surface of the capsule at T = -2 ns. If the capsule transmission is $\geq 1\times10^{-4}$ then the pre-pulse may be strong enough to cause imprint.

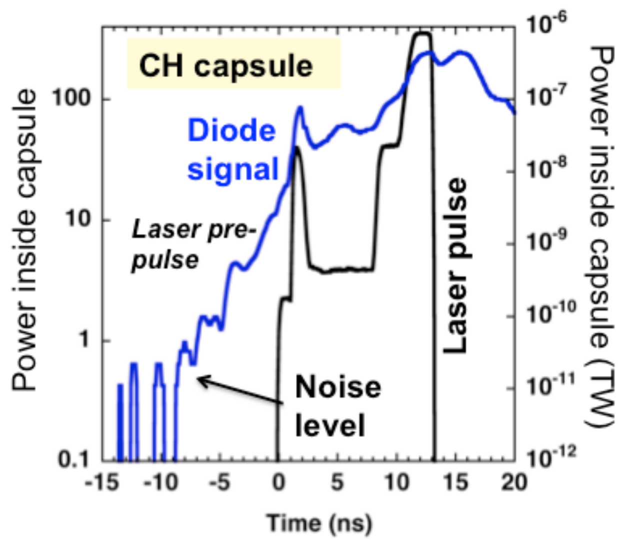

Figure 4. Plot shows the laser pulse and diode signal for a hohlraum with a CH capsule. Note the gradual rise of the diode signal from T = -8 ns to T = 0 due to laser prepulse.

The photometrics used to estimate the total power reaching the inside of the capsule is as follows: The diode samples a 1/506 fraction of the beam area that reaches the first mirror. The VISAR optics collects light in an f/3 cone angle from inside the capsule. Assuming the light is isotropic inside the capsule means that VISAR collects a 1/147 fraction of the total. The 351 nm bandpass filter transmits 60% and the diode sensitivity at 351 nm is 36 mA/W. Combining these gives a Voltage-to-Power scaling of 6.9×10^4 Watts/Volt.

These initial measurements raised several questions which led to experimental tests. For example, we tested whether the signals were being contaminated with 1054 nm (1-w) unconverted light (which floods the target chamber and strikes parts of the target) by adding 3 mm of KG3 colored glass. This filter adds 10^4 times of attenuation to any 1054 nm light. Comparing signals on similar shots with and without the KG3 filter shows essentially no change. Adding a beam block in front of the diode showed that there was no contamination by electrical noise. Replacing the 351 nm bandpass filter with a 480 nm bandpass provided a test for thermal background emission. Figure 5 shows the signal detected using the 480 nm bandpass. The signal id dominated by noise until the laser turns on and then shows a small evolving signal that increases to about 1/10 of the signal obtained using the 351 nm bandpass at about T = 5 ns. The expected reduction in black-body emission from 351 nm to 480 nm is about 30%. In addition, the diode is less sensitive at 480 nm giving an overall expected signal reduction of about a factor of 7. This is close to the measured factor of 10 and suggests that thermal emission is detected by the diode signal.

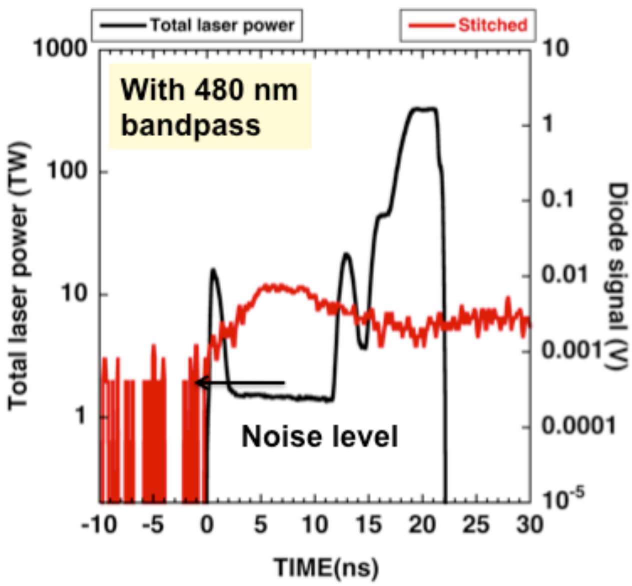

Figure 5. Diode signal with a 480 nm bandpass filter.

Additional measurements are in progress to verify where the signal comes from in the hohlraum. Light from the periphery of the hohlraum does not couple into the VISAR line of sight. However, there is a blast shield in front of the VISAR collection lens which is changed every other shot. It's possible for light to scatter off debris on this shield and couple into the VISAR line of sight. This would likely lead to significant fluctuations in the diode signal which are not observed.

Measurements also show a spike in the diode signal during the initial laser turn-on. The spike is visible in Fig. 4 at the start of the laser power. The peak of the spike tends to occur shortly after the laser peak for CH capsules but occurs during the rise for HDC capsules. Transmission of 351 nm through CH may be significantly less than through HDC; this could mean that the CH signal is more indicative of the radiation temperature while the HDC is indicative of glint. Further investigations of these signal differences are ongoing.

IV. Conclusions

A simple high-dynamic range optical signal detector has been added to the VISAR instrument making it possible to detect laser pre-pulse at the target and laser glint that reaches the capsule. Several experimental tests have ruled out 1054 nm light and electrical signal contamination. Changing the bandpass filter indicates signal contribution from thermal emission. An outstanding question is where the light is coming from that couples into the diode. Further tests will aim to determine the signal origin as well as use measurements of capsule transmission to 351 nm light to quantify the level of pre-pulse and glint.

V. Acknowledgements

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